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Original research article

Comparison of bond strength of metallic and ceramic orthodontic brackets to enamel: an *in vitro* study

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Abstract

Objective: Adhesive systems used with brackets should provide sufficient bond strength to withstand forces during mastication and orthodontic treatment. The purpose of this *in vitro* study was to assess the shear bond strength (SBS) and failure sites of different metallic and ceramic brackets by two different bonding systems.

Materials and Method: Sixty-eight caries-free human mandibular premolars were randomly assigned to 4 groups of 17 each. Group 1 consisted of metallic brackets bonded with Transbond XT; Group 2 consisted of metallic brackets bonded with Clearfil S3 Bond Plus; ceramic brackets bonded with Transbond XT and Clearfil S3 Bond Plus composed Groups 3 and 4, respectively. A universal testing machine was used to determine the SBS, and the adhesive remaining after debonding was assessed using an adhesive remnant index (ARI).

Results: The bond strength of metallic brackets was significantly lower than the ceramic ones. Ceramic brackets bonded with Clearfil S3 Bond Plus declared the highest bond strength ($p<0.001$), revealing a mode of bond failure at the enamel-adhesive interface. However, the mode of failure for the conventional system was cohesive at the composite interface, showing a statistically significant difference between groups ($p<0.05$).

Conclusion: Although all bonding systems provided adequate SBS values, Clearfil S3 Bond Plus requires a careful clinical application due to high bond strength and ARI scores. In relation to present findings, the conventional bonding system could be more suitable when ceramic brackets are bonded to enamel surface. Metal brackets can be bonded safely with both bonding systems.

Keywords: Bond strength; brackets; ceramic; metal; orthodontic adhesives; orthodontic appliances; orthodontics

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Introduction

Metallic brackets are the most commonly used brackets during fixed orthodontic treatment, but the metallic appearance is not acceptable for most patients. In recent years orthodontic patients have become more aware of the importance of esthetic appearance. Therefore, companies have changed their focus towards esthetic solutions in order to meet patients' demands for esthetics. Since the introduction of ceramic brackets, their design and clinical performances have been greatly improved.[1]

Adhesive systems used with brackets should provide sufficient bond strength to withstand forces during mastication and orthodontic treatment, but also avoid unwanted effects during debonding.[2] Very high bond strengths are undesirable because patient discomfort and/or enamel damage may be encountered.[3] Minimum bond strength required for bonding brackets has been suggested to be in the range 6-8 MPa.[4] It was declared that the ideal bond strength should be less than the breaking strength of the enamel which is approximately 14 MPa.[5] The bond strength of metallic brackets has been evaluated previously by using different bonding systems.[6-10] Redd and Shivapuja[11] reported that enamel damage was more likely to result from debonding ceramic brackets than from metallic brackets. As ceramic brackets do not bend during debonding, most bond failures were generated at the enamel-adhesive interface.[11] In relation, the concern is whether the bond is too strong with ceramic brackets for safe debonding as declared by Bishara.[12]

The aim of this *in vitro* study was to investigate the relationship between the shear bond strengths (SBS) of metallic and ceramic brackets bonded to enamel by using a conventional technique and a new bonding system, Clearfil S^3 Bond Plus. The hypothesis to be tested is that there would be statistically significant differences between (1) the SBS, and (2) the site of bond failure of

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metallic and ceramic brackets bonded with the conventional bonding system or Clearfil S³ Bond Plus.

Materials and Method

A total of sixty-eight caries-free human mandibular premolars, extracted for orthodontic reasons were used in this study. The criteria for tooth selection included intact buccal enamel that had not been pre-treated with chemical agents, no visible cracks, no carious lesions, no restorations or enamel irregularities. The teeth were stored in distilled water with thymol crystals (1% wt/vol) added to inhibit bacterial growth at room temperature after extraction. The teeth were cleaned and polished with a fluoride-free pumice slurry and rubber cups for 10 sec, washed thoroughly and dried with an oil-free air stream and examined under a light stereomicroscope at ×10 magnification to ensure the absence of caries and enamel cracks. All teeth were embedded vertically in cold-curing acrylic (Orthocryl, Dentaurum, Ispringen, Germany) using metal ring moulds. The sample was randomly assigned to four groups of 17 teeth each using random numbers table, and the brackets were bonded. The average base surface area of the brackets was calculated by the measurements made by a digital caliper (Mitutoyo, Miyazaki, Japan). The mean base surface area was calculated as 10.90 mm^2 for the metal and 10.45 mm^2 for the ceramic brackets. Bonding procedure was performed in the following manner:

Group 1 with premolar metal brackets (Avex Suite Mx, Opal Orthodontics, Ultradent, USA) utilized the conventional bonding with Transbond XT primer (3M Unitek Orthodontic Products, Monrovia, CA, USA). The enamel surfaces were etched with 37% phosphoric acid gel (Gel Etch, 3M Unitek, Monrovia, CA, USA) for 15 sec. The primer was rubbed with pressure onto the enamel surface of each tooth for 5 sec and dried with an oil and moisture-free air stream. The metal brackets were coated with Transbond XT adhesive paste and positioned at the center of the buccal surface. The excess adhesive was removed from the margins of the bracket base with a scaler before polymerization. All brackets were light-cured for 40 sec with a halogen curing unit (Hilux Ultra Plus, Benlioğlu Dental, Ankara, Turkey), 10 sec from each of the mesial, distal, gingival and occlusal margins.

The teeth in Group 2 with premolar metal brackets (Avex Suite Mx, Opal Orthodontics, Ultradent, USA) were bonded by Clearfil S³ Bond Plus (Kuraray Medical Inc, Okayama, Japan). The enamel surfaces were etched with 37% phosphoric acid gel (Gel Etch, 3M Unitek, Monrovia, CA, USA) for 15 sec. Then, the teeth surfaces were washed with water and dried with an oil and moisture-free air stream. The bond was applied with rubbing pressure onto the enamel surface for 10 sec and air-dried for another 10 sec. The metal brackets were coated with Transbond XT adhesive paste and positioned at the center of the buccal surface as in Group 1. The excess adhesive was removed from the margins of the bracket base with a scaler before polymerization. All brackets were light-cured for 40 sec with a halogen curing unit (Hilux Ultra Plus), 10 sec from each of the mesial, distal, gingival and occlusal margins.

Groups 3 and 4 were treated the same as Groups 1 and 2, respectively, except that ceramic brackets (Avex Suite Cxi, Opal Orthodontics, Ultradent, USA) instead of metallic brackets were bonded to the teeth.

All specimens were stored in distilled water at room temperature for 24 h. Shear bond testing was performed with a universal testing machine (Instron Co, Canton, MA, USA). The specimens were stressed in an occlusogingival direction with a crosshead speed of 1 mm/min. The maximum load necessary to debond each bracket was recorded in Newton and then converted into Megapascal (MPa) by dividing the calculated Newton value to bracket base area.

The debonded enamel surfaces were examined under a stereomicroscope (Nikon, Osaka, Japan) at ×20 magnification to assess the residual adhesive remaining on the tooth surface by a blinded examiner (ÇU). A modified adhesive remnant index (ARI) was used to quantify the amount of the remaining adhesive on the tooth surface. The following scale was used; 1: all the adhesive remained on tooth, 2: more than 90% of the adhesive remained on tooth, 3: between 10-90% of adhesive remained on tooth, 4: less than 10% of the adhesive remained on tooth, 5: no adhesive remained on tooth.

Statistical analysis

Statistical evaluation was performed by SPSS for Windows version 16.0 (SPSS Inc., Chicago, IL, USA). Descriptive statistics including the mean, standard deviation, minimum and maximum values were calculated for each group. The one-sample Kolmogorov-Smirnov test was applied in order to evaluate the normal distribution of variances. Comparisons of bond strength data were performed by one-way analysis of variance (ANOVA). Follow-up analysis were performed by post-hoc Tukey honestly significant difference (Tukey HSD) multiple comparison test. Kruskal-Wallis test was used to determine significant differences in the ARI scores among the groups. The level of significance was established as $p<0.05$.

Results

Shear bond strength

Table 1 shows the descriptive statistics of the SBS data, including mean, standard deviation, minimum, maximum and the 95% confidence interval. The results of ANOVA revealed statistically significant differences in bond

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Table 1. *Descriptive statistics related to shear bond strength data*

		n	Mean (MPa)	SD	Min	Max	95% Confidence interval Lower bound	Upper bound
Metal brackets	Group 1	17	9.59	1.12	7.21	11.10	9.01	10.16
	Group 2	17	10.52	0.79	9.39	12.10	10.11	10.93
Ceramic brackets	Group 3	17	12.18	1.11	9.98	14.20	11.60	12.75
	Group 4	17	13.77	2.11	10.20	17.70	12.69	14.85

Group 1: Transbond XT, Group 2: Clearfil S3 Bond Plus, Group 3: Transbond XT, Group 4: Clearfil S3 Bond Plus
n: Sample size; MPa: Megapascal; SD: Standard deviation.

strength, with the highest mean SBS in Group 4 (Table 2). The lowest mean SBS was 9.59±1.12 MPa which was recorded in Group 1. The Tukey HSD test showed that the bond strengths of Group 3 (12.18±1.11 MPa) and Group 4 (13.77±2.11 MPa) were significantly greater than that in Group 1 (9.59±1.12 MPa, $p<0.001$). Similarly, mean SBS of Group 2 (mean: 10.52 ±0.79 MPa) was significantly lower than Group 3 and Group 4 with a significance of $p<0.005$ and $p<0.001$, respectively (Table 2). Therefore, the first hypothesis was not rejected. A significant difference was found between Groups 3 and 4, where ceramic brackets were bonded with the conventional system and Clearfil S^3 Bond Plus, revealing higher values in Group 4 ($p<0.05$).

Adhesive remnant index

The failure modes of the specimens are shown in Table 3. The Kruskal-Wallis test revealed significant difference in the ARI scores of the groups with a $\chi^2=8.05$, $p=0.045$. Mann-Whitney U-test showed significant differences between Groups 1 and 4 ($p<0.05$). Thus, the second hypothesis of this study was not rejected. The predominant mode of failure for the metal brackets bonded with the conventional system was cohesive failure within the adhesive so that the adhesive remained partly on the bracket base and partly on the enamel surface. Conversely, Group 4 exhibited bond failure at the enamel-adhesive interface.

Discussion

In vitro investigations of bond strength provide beneficial guidance for the clinicians in the selection of new adhesive and bracket systems.[13] Reynolds[4] reported that a minimum bond strength of 6-8 MPa is adequate for most clinical orthodontic needs, because this provides sufficient strength to withstand masticatory and orthodontic forces during orthodontic treatment. Although ceramic brackets provide adequate esthetics and clinical performance, many clinicians still concern about their bond strength due to the possibility of creating enamel cracks during debonding. Uysal *et al.*[1] have reported that the use of self-etching primer systems in bonding ceramic brackets provide lower bond strength values than the conventional acid-etching method. Similarly, a recently developed, amorphous calcium phosphate-containing composite system has been rec-

Table 2. *Pairwise comparison of the SBS values of the groups*

Group	Group	Mean Difference (MPa)	Std Error	Significance	95% Confidence Interval Lower bound	Upper bound
1	2	-0.93	0.47	0.313	-2.22	0.35
	3	-2.59	0.43	0.000***	-3.87	-1.30
	4	-4.18	0.34	0.000***	-5.47	-2.90
2	1	0.93	0.59	0.313	-0.35	2.22
	3	-1.65	0.25	0.005**	-2.94	-0.37
	4	-3.25	0.44	0.000***	-4.53	-1.96
3	1	2.59	0.18	0.000***	1.30	3.87
	2	1.65	0.51	0.005**	0.37	2.94
	4	-1.60	0.42	0.007*	-2.88	-0.31
4	1	4.18	0.77	0.000***	2.90	5.47
	2	3.25	0.38	0.000***	1.96	4.53
	3	1.60	0.46	0.007*	0.31	2.88

Group 1: Transbond XT, metal bracket; Group 2: Clearfil S3 Bond Plus, metal bracket; Group 3: Transbond XT, ceramic bracket; Group 4: Clearfil S3 Bond Plus, ceramic bracket.
**p< 0.05; **p<0.01; ***p<0.001; p>0.05, non-significant.*

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Table 3. *ARI Scores for all groups*

ARI Score	Group 1	Group 2	Group 3	Group 4
1	4	3	1	0
2	3	2	3	2
3	3	3	4	3
4	6	7	5	8
5	1	2	4	4

χ^2= 8.05, p=0.045.
Group 1: Transbond XT, metal bracket; Group 2: Clearfil S3 Bond Plus, metal bracket; Group 3: Transbond XT, ceramic bracket; Group 4: Clearfil S3 Bond Plus, ceramic bracket.

ommended for ceramic brackets.[14] A review of the literature revealed that no research has been published that compared the bond strength of ceramic brackets bonded with a recently developed system, Clearfil S[3] Bond Plus. This bonding system was claimed by the manufacturers to enhance an improved working time, and also include fluoride-releasing property. The present study, which was performed to evaluate the SBS of metallic and ceramic brackets with traditional bonding technique *versus* the new fluoride-releasing bonding system, revealed that both systems provided adequate SBS values. The current SBS values in metallic groups were higher than the minimum values, and lower than maximum values as recommended.[4,5] According to the results, bond strength of ceramic brackets exhibited higher values than that of metallic brackets, which was consistent with earlier investigations.[1,15,16] On the contrary, Korbmacher *et al.*[17] reported that the bond strength of metallic brackets were higher than ceramic brackets, coinciding with the results of a recent study by Mirzakouchaki *et al.*[18] Additionally, Habibi *et al.*[19] found that the mean debonding strength for the metal brackets was higher than that for ceramic brackets. These differences in bond strength reveal large variations among studies which might be attributed to the differences in selection of specimens, storage conditions of the teeth, morphology of the tooth surfaces, enamel surface preparation, type of brackets, mode of testing and different kinds of adhesives used in studies.[18-21]

Present results declared that, ceramic brackets bonded with Clearfil S[3] Bond Plus showed significantly higher bond strength than those bonded with Transbond XT, which was close to the breaking strength of the enamel that might reveal a possible risk of enamel damage during debonding.[5] However, lower SBS values with the conventional bonding system for ceramic brackets also provide clinically acceptable values.

With respect to the ARI scores, the predominant mode of bracket failure was mostly at the enamel-adhesive resin interface with Clearfil S[3] Bond Plus system revealing greater stress applied to the enamel surface. This is in contrast with other investigations that showed high incidence of bond failure at the bracket-adhesive interface and within the adhesive for ceramic brackets.[22,23] Bond failure at the bracket-adhesive interface or within the adhesive is more desirable than that at the enamel-adhesive resin interface.[21] We believe that although high SBS during treatment and shorter chairtime for residual resin removal during debonding would be beneficial in clinical situations, cohesive failure within the adhesive may be desirable because of less damage or fracturing of the enamel after debonding especially in ceramic brackets. However, current results with traditional bonding system showed that the remaining adhesive on teeth after debonding involves mostly the cohesive failure within the adhesive. This is desirable because the risk of enamel fracture is reduced during debonding.

Results of *in vitro* studies of bond strength should always be interpreted with caution due to the difficulties in simulating the nature of oral environment. Complexitiy of the oral environment include differences in temperature, stresses, dental plaque and other factors which may alter the efficiency of adhesives.

CONCLUSION

All groups displayed clinically acceptable mean bond strengths for orthodontic treatment, with higher bond strength in ceramic brackets in comparison to metallic brackets. Ceramic orthodontic brackets bonded with Clearfil S[3] Bond Plus showed higher mean bond strength than those bonded with Transbond XT, which was close to the maximum SBS values, and may not be desirable because of the possible risk of enamel damage during debonding. Conventional bonding system provides a lower, but acceptable bond strength in ceramic brackets which may be more suitable in clinical application. The pattern of bond failure was at the enamel-adhesive resin interface with Clearfil S[3] Bond Plus bonding system, whereas the predominant mode of failure for the conventional bonding system was mostly cohesive failure within the adhesive.

Conflict of interest disclosure: The authors declare no conflict of interest related to this study.

REFERENCES

1. Uysal T, Ustdal A, Kurt G. Evaluation of shear bond strength of metallic and ceramic brackets bonded to enamel prepared with self-etching primer. Eur J Orthod 2010;32:214-8.

2. Ryu C, Namura Y, Tsuruoka T, Hama T, Kaji K, Shimizu N. The use of easily debondable orthodontic adhesives with ceramic brackets. Dent Mater J 2011;30:642-7.

3. Millett DT, Glenny AM, Mattick RCR, Hickman J, Mandall NA. Adhesives for fixed orthodontic bands. Cochrane Database of Systematic Reviews 2007;2:CD004485.

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4. Reynolds IR. A review of direct orthodontic bonding. Br J Orthod 1975;2:171-8.

5. Turgut MD, Attar N, Korkmaz Y, Gokcelik A. Comparison of shear bond strengths of orthodontic brackets bonded with flowable composites. Dent Mater J 2011;30:66-71.

6. Linklater RA, Gordon PH. Bond failure patterns in vivo. Am J Orthod Dentofacial Orthop 2003;123:534-9.

7. Minick GT, Oesterle LJ, Newman SM, Shellhart WC. Bracket bond strengths of new adhesive systems. Am J Orthod Dentofacial Orthop 2009;135:771-6.

8. Cehreli ZC, Kecik D, Kocadereli I. Effect of self-etching primer and adhesive formulations on the shear bond strength of orthodontic brackets. Am J Orthod Dentofacial Orthop 2005;127:573-9.

9. Arhun N, Arman A, Sesen C, Karabulut E, Korkmaz Y, Gokalp S. Shear bond strength of orthodontic brackets with 3 self-etch adhesives. Am J Orthod Dentofacial Orthop 2006;129:547-50.

10. Attar N, Taner TU, Tülümen E, Korkmaz Y. Shear bond strength of orthodontic brackets bonded using conventional vs one and two step self-etching/adhesive systems. Angle Orthod 2007;77:518-23.

11. Redd TB, Shivapuja PK. Debonding ceramic brackets: effects on enamel. J Clin Orthod 1991;25:475-81.

12. Bishara SE. Ceramic brackets and the need to develop national standards. Am J Orthod Dentofacial Orthop 2000;117:595-7.

13. Oztaş E, Bağdelen G, Kiliçoğlu H, Ulukapi H, Aydin I. The effect of enamel bleaching on the shear bond strengths of metal and ceramic brackets. Eur J Orthod 2012;34:232-7.

14. Uysal T, Ustdal A, Nur M, Catalbas B. Bond strength of ceramic brackets bonded to enamel with amorphous calcium phosphate-containing orthodontic composite. Eur J Orthod 2010;32:281-4.

15. Joseph VP, Rossouw E. The shear bond strengths of stainless-steel and ceramic brackets used with chemically and light-activated composite resins. Am J Orthod Dentofacial Orthop 1990;97:121-5.

16. Mundstock KS, Sadowsky PL, Lacefield W, Bae S. An in vitro evaluation of a metal reinforced orthodontic ceramic bracket. Am J Orthod Dentofacial Orthop 1999;116:635-41.

17. Korbmacher H, Klocke A, Huck L, Kahl-Nieke B. Enamel conditioning for orthodontic bonding with a single step bonding agent. J Orofac Orthop 2002;63:463-71.

18. Mirzakouchaki B, Kimyai S, Hydari M, Shahrbaf S, Mirzakouchaki-Boroujeni P. Effect of self-etching primer/adhesive and conventional bonding on the shear bond strength in metallic and ceramic brackets. Med Oral Patol Oral Cir Bucal 2012;17:e164-70.

19. Habibi M, Nik TH, Hooshmand T. Comparison of debonding characteristics of metal and ceramic orthodontic brackets to enamel: an in-vitro study. Am J Orthod Dentofacial Orthop 2007;132:675-9.

20. Theodorakopoulou LP, Sadowsky PL, Jacobson A, Lacefield W Jr. Evaluation of the debonding characteristics of 2 ceramic brackets: an in vitro study. Am J Orthod Dentofacial Orthop 2004;125:329-36.

21. Bishara SE, Olsen ME, VonWald L. Evaluation of debonding characteristics of a new collapsible ceramic bracket. Am J Orthod Dentofacial Orthop 1997;112:552-9.

22. Bishara SE, Fonseca JM, Boyer DB. The use of debonding pliers in the removal of ceramic brackets: force levels and enamel cracks. Am J Orthod Dentofacial Orthop 1995;108:242-8.

23. Blalock KA, Powers JM. Retention capacity of the bracket bases of new esthetic orthodontic brackets. Am J Orthod Dentofacial Orthop 1995;107:596-603.

Seramik ve metal ortodontik braketlerin mine yüzeyine bağlanma kuvvetlerinin incelenmesi: *in vitro* bir çalışma

Özet

Amaç: Braketleri diş yüzeyine yapıştırmakta kullanılan adeziv sistemler, ortodontik tedavi sırasında ve çiğneme esnasında oluşan kuvvetlere karşı yeterli dayanıklılığı göstermelidir. Bu *in vitro* çalışmanın amacı, iki farklı yapıştırma sistemi ile yapıştırılan metal ve seramik braketlerin çekme-bağlanma kuvvetlerini ve diş yüzeyindeki kopma alanlarını incelemektir.

Gereç ve Yöntem: Altmış sekiz çürüksüz alt küçükazı diş rastgele 17'şer dişten oluşan 4 gruba bölünmüştür. 1. Grup; metal braketler Transbond XT ile, 2. Grup; metal braketler Clearfil S3 Bond Plus ile, 3. Grup; seramik braketler Transbond XT ile, 4. Grup; seramik braketler Clearfil S3 Bond Plus ile yapıştırılmıştır. Universal test cihazı ile çekme-bağlanma kuvvet değerleri ve sonrasında diş yüzeyinde kalan artık adeziv miktarı ölçülmüştür.

Bulgular: Metalik braketlerin bağlanma kuvvetleri seramik braketlerden istatistik olarak daha düşüktür. Clearfil S3 Bond ile bağlanan seramik braketler en yüksek ortalama bağlanma kuvvetini göstermişlerdir ($p<0.001$) ve kopma mine-adeziv yüzeyinde gerçekleşmiştir. Ancak, geleneksel yapıştırma sisteminde koheziv bağlantı hatası kompozit ile diş arasında gerçekleşmiştir ve bu durum gruplar arasında istatistiksel olarak önemli bir fark oluşmasına neden olmuştur ($p<0.05$).

Sonuç: Bütün yapıştırma sistemleri yeterli bağlanma kuvveti göstermişlerdir fakat yüksek bağlanma kuvvetinden ve ARI skorundan dolayı Clearfil S3 Bond Plus dikkatli kullanılmalıdır. Bu bulgulara dayanarak, geleneksel yapıştırma sistemlerinin seramik braketleri yapıştırmak için daha uygun olduğu sonucuna varılabilir. Metal braketler ise her iki sistemle de yapıştırılabilir.

Anahtar Kelimeler: Bağlanma kuvveti; braketler; metal; ortodonti, ortodontik gereçler, ortodontik yapıştırıcılar; seramik

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